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Operational forecasting of a 'wind-chill' factor for young lowland lambs

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Summary

As part of a study to obtain detailed veterinary and economic information on lamb mortality in a commercial lowland sheep flock, meteorological observations were made at Rushall Manor Farm, near Reading, between 1976 and 1979.

The data were interpreted in terms of critical environmental heat demands likely to lead to lamb mortality 'in the field'. Since 1980 these 'critical demands' have been used as a basis for lamb 'wind-chill' forecasting trials in south and south-west England in collaboration with forecasting offices.

Introduction

'... there is hardly an expense equal to the effects, both to fields and livestock, of a gnawing or destroying air.' (L. Bain, *Q J Agric,* 1839).

Early in 1976 the Divisional Veterinary Officer (Veterinary Investigations) for South East ADAS at Reading approached the recently established Regional Agrometeorological Department with a view to a collaborative study of the veterinary and economic aspects of lamb mortality in a nearby commercial lowland sheep flock.

Lamb mortality, during and soon after birth, is thought to be a major source of loss to the world's sheep industry. Various studies have been made in Australia, New Zealand and Scotland (e.g. Scottish Agricultural Colleges, 1975). Although some figures are available from the Meat and Livestock Commission for 504 commercial lowland sheep flocks in 1970 and 1971 (suggesting a lamb birth-to-weaning mortality of 13%), and a Ministry of Agriculture, Fisheries and Food survey in the south of England for 1974 and 1975 indicated that on many farms lamb losses from birth to six weeks were considerable (20% or more), little detailed information has been published on the situation in England and Wales.

Farm livestock can be affected by climate both indirectly, through the influence of climate upon the availability of food, and directly, as a result of exposure to the rigours of climate (e.g. Blaxter 1964, Obst and Ellis 1977). The rate of metabolic heat production in homeothermic animals such as lambs increases

*ADAS — Agricultural Development and Advisory Service — the advisory branch of the Ministry of Agriculture, Fisheries and Food (MAFF)
WOAD — Welsh Office Agriculture Department

in response to an increase in heat loss to the environment and represents an attempt to stabilize body temperature. Heat loss increases as environmental temperature falls and as air movement and evaporation from the coat increase (Joyce *et al.* 1966). The environment becomes potentially lethal for the lamb when its heat loss exceeds its 'summit metabolism' — the maximum rate of heat production that the lamb can sustain.

Clearly the total environmental effect experienced by a lamb will fluctuate from hour to hour and follows variations in air motion, temperature, radiative effects and the intensity and duration of rainfall, as has been demonstrated, for example, by Slee (1977) and McArthur and Monteith (1980) in measurements of the (electrical) energy required to maintain the temperature of a simulated animal; by Alexander (1964) in climate-chamber research; and by Sykes *et al.* (1976) in field observations. Such investigations imply that almost all new-born lambs are subject to cold-stress (and a high metabolic demand) which is compounded by low body (energy) reserves with which to meet the demand. An erosion of energy reserves from an already undernourished or sick lamb, particularly in breeds with short birth-coats, is recognized as contributing to the incidence of death in young lambs. In severe climates, associated with, for example, hill farms, cold-stress might be the primary cause of death in new-born lambs (Munro 1962).

Such weakling stock might be at risk even in apparently moderate weather conditions such as those generally encountered in south-east England; it is this hypothesis that was investigated and from which the wind-chill forecasting system developed.

Materials and methods for the investigation

The farm

Rushall Manor Farm lies mainly on a south-facing, undulating slope of the Berkshire Downs (some 17.5 km west of Reading) leading down to the River Pang. Of the 250 ha a large part is under cereals, about 40 ha are temporarily under grass (leys) and 16 ha are permanent pasture.

The flock

The sheep flock in 1976 consisted of 400 breeding ewes of four different types (mainly Cadzows and Suffolk Crosses). In 1977 the flock size was increased to 486 by a batch of Scott half-bred gimmers (ewes lambing for the first time); in 1978 it was further increased to 550, and in 1979 to 567.

All dead lambs were submitted for autopsy; careful records being kept of date of death, age, and ewe of origin. Where death was attributed to chilling or starvation in the field, carcases showed general congestion of the viscera, especially the lungs, and in most cases the stomachs were empty or contained only a little milk. Table I presents the numbers and percentages of total lamb losses due to chilling or starvation in the field over the years of the study.

Table I. *Analysis of lamb losses over the period of study, 1976–79*

	1976	1977	1978	1979
Ewes	400	486	550	567
Total lambs born	745	943	1150	1133
Total field and house losses	85	116	209	238
Chilling/starvation losses in the field	6 (7%)	20 (17%)	36 (17%)	77 (32%)

Equipment

In field investigations designed to evaluate the effect of meteorological factors on livestock, long-term interdisciplinary studies are commonly desirable. Equally, an agriculturalist will commonly require a

swift resolution of a production problem which is having, or could have, important economic consequences. Logistically, too, there are difficulties in supervising and maintaining site-monitoring equipment and in achieving adequate data-recovery regularly over an extended period (Smith 1970). Changes from year to year in grazing facilities, husbandry techniques, etc., add further dimensions of difficulty. However, it was Gloyne's conviction (Gloyne 1967) that, given a sufficiency of 24–hour runs, it should at least be possible to infer the basic features of the surface wind regime at any site after periods of study reckoned in weeks rather than years.

'Run-of-wind' measuring equipment (cup anemometers) exposed at 2 m height and minimum thermometers at 1 m were established in several fields near ewe feed and watering areas and near significant hollows. Surveys with hand-held anemometers helped to establish a preliminary view of the association between local land form and local wind speed and direction. Data were related to a 'reference site' which housed a rain-gauge, a run-of-wind anemometer, a grass-minimum thermometer, maximum and minimum thermometers and a thermograph housed in a large (Stevenson) screen at lamb height, and a minimum thermometer, screened simply and exposed at 1 m as in the other fields. During the critical neonatal period daily readings were made. Subsequently, in 1978 and 1979, continuous meteorological recordings were made at lamb height using automatic equipment. The representativeness of such fixed-point data in the present context may be open to question. The data can only provide an approximation to the actual environment experienced by a lamb possibly protected by its ewe or otherwise sheltered. However, such data, even if not correct on an absolute scale, still provide a means of estimating days of relatively high or low environmental stress.

Heat loss from lambs

Data obtained by Alexander (1964) and Smith (1973) provided the basis for expressing the environmental variables in terms of heat loss from the young lamb. From Fig. 1 of Alexander (1964) it may be deduced, for example, that the rate of heat loss (M) from a young, dry, 2 kg lamb, with a fine coat, in still air at −32 °C (M = 160 W m^{-2}) is the same as that from the same lamb with a dry coat in a 5.5 m s^{-1} (12 miles per hour) wind and at an air temperature of −4 °C, or with a wet coat in a 5.5 m s^{-1} wind when the air temperature is +13 °C. The influences of wind and particularly a wet birth-coat are clear. Corrections to the environmental temperature T_a can be made to allow for a 'radiative environment' most apparent under clear-sky conditions. Smith (1973) suggests decreasing T_a by up to 5 °C depending on cloud cover, and such corrections were applied before estimating M. Although Alexander's work was on young merino lambs, the results were taken as applicable to the Rushall Manor lamb flock, a not unreasonable assumption according to Alexander (personal communication 1978).

In 1978 the environmental heat demand from the lambs over four-hourly periods was estimated as a multiple of the basal 'metabolic' rate of heat loss per hour (the rate of heat production for the lamb in its 'thermal comfort zone'), M_B, from the observed combination of wind, temperature and rainfall (it being assumed that rainfall wetted the coat instantly and that the cessation of rain similarly marked the return of the birth-coat to the dry state). The heat loss estimates were accumulated for one, two and three days prior to lamb death and tabulated against the total numbers of lamb field deaths occurring within equal increments of the cumulative energy demand M_p over the appropriate period, p. If the observed deaths are not weather related, every day would hold an equal probability for the death of lambs. M_p was therefore calculated for every day and deaths allocated in proportion to the number of days with a given range of energy demand to give an 'expected' death distribution. Since the dead lambs were recovered only once daily in 1978, the time of death is in question; the assumption was made that all lamb deaths occurred overnight. In 1979 hourly estimates of the heat demands were made — and lambs were recovered twice daily (confirming that deaths indeed occurred predominantly overnight).

A full description of the weather and details of lamb mortality over the years 1976–79 is to be found in Starr (1981). The tables presented there may be summarized as follows:

(i) Field deaths are predominantly in twins and triplets and are highly correlated with the heat loss accumulated 24 hours before death.

(ii) Negative (or only small positive) weight gains are generally recorded in lamb deaths where the animal is under 10 days old.

(iii) Mortality is not confined predominantly to any one field.

It is of interest to study the energy considerations for lamb survival. Alexander (1964) states that summit metabolism in young merinos (3 kg lambs) is 58 W or 232 W m^{-2} (i.e. about four times the basal metabolic rate M_B). In the present study, the maximum hourly energy demand was estimated to be 4.4 M_B and the corresponding demands over 12 and 24 hours to be 49 and 94 M_B respectively, environmental demands which, over the day, are close to the summit demand and which exceed this demand over short periods. Total useful energy reserves in lambs from adequately fed ewes are about 1083 J kg^{-1} (i.e. 3.135 kJ for a 3 kg lamb); the time to exhaust fat and glycogen reserves is hence of the order of 15 h. Eales (1980) further points out that twins each weighing 3 kg have something like 30% more surface area through which heat is lost than a single 6 kg lamb; in addition the twins have to compete for the available milk supply.

The low, generally negative, liveweight gains in the young lambs point to the energy intake being unable to match the energy lost to the environment; this continual erosion of energy, even if not fatal, is reflected in low liveweight gain and hence in the sale weight of the fat lamb.

The Rushall Manor lambs were housed during the critical first day and in general were subjected to an altogether more moderate climate than that which can give trouble to upland flocks. Nevertheless, the data indicated that there is a difference between observed and expected young lamb mortality. The implication is that young lambs (particularly twins or triplets), less than 10 days old, can be at risk even in quite moderate weather.

Being more specific, the 1979 analyses showed that some 60% of lamb deaths were attributable to days when the integrated heat demand over 24 hours (M_{24}) exceeded 80 times the basal rate (M_B); the corresponding demand above which 75% of deaths occurred was 70 M_B. Taking the total mortality in day-old lambs over the eight 24-hour periods with M_{24} greater than 80 M_B, the mortality of light (less than 3 kg), medium (3–5 kg) and heavy (more than 5 kg) lambs is found to be 14.5, 5.2 and nil (expressed as percentages of their respective populations of 48, 171 and 35). On one night, 13/14 March, 6 of the 14 (i.e. 43%) light lambs died; only 6 out of 51 medium lambs died. None of the 4 heaviest succumbed.

The practical implications of the critical 24-hour heat demand of 80 M_B mentioned for young lambs may, by reference to Alexander's (1964) Fig. 1, be summarized as follows.

Wet lambs may be in danger in winds of about 5 m s^{-1} even at a temperature of about +20 °C; the corresponding 'danger' temperature for dry lambs under these windy conditions is 0 °C. Even a wind of below 2.5 m s^{-1} can cause distress to wet lambs when the temperature is below 10 °C (clear skies accentuate the danger). The temperature must be below −10 °C if dry lambs are to be at risk in tranquil conditions. (Calculations show that this 24-hour heat demand of 80 M_B was attained on at least 15 occasions in northern England and the Borders in March and April 1979.)

The forecasting of the heat loss factor ('wind-chill') and field assessments

1980 and 1981 seasons

In the springs of 1980 and 1981, trial daily forecasts of likely hazardous weather for young lambs were prepared for the Rushall Manor area with the co-operation of the meteorological offices at RAF Benson

(Oxon) and RAF Upavon (Wilts). Briefly, the 24 hours beginning 0800 local time were divided into 6 four-hourly periods, for which temperatures and wind speed (reduced to lamb height in the Rushall Manor area) and the occurrence or not of rain were forecast. Wind-chill indices were totalled (Table II(a) and (b)) and passed by telephone to the farm manager, Mr Bishop, whose initiative it was to make contact. Should a 'danger' level be attained (M greater than or equal to 80 M_B) the decision might be, for example, to keep young lambs housed for a further day or so. An example of the forecast (and actual) wind-chill for 27 March 1980 is shown in Table II(c). The forecasts were followed meticulously in 1981; the farm manager reported only 1% field losses in 1000 lambs. In particular, on the severe night of 21 March, 43 deaths occurred at an elevated farm near Marlborough; no fatalities occurred at Rushall Manor Farm. Upavon forecast the high wind-chill factor of 99 and Mr Bishop reacted accordingly.

Table II. *Wind-chill indices for wet coat and dry coat*

Wind speed at Rushall Manor Farm	(a) Wet coat indices				(b) Dry coat indices		
	Temperature (°C)						
($m\ s^{-1}$)	5	5 to 0	0 to −5	< −5	> 0	0 to −5	< −5
>10	17	18	19	20	12	13	15
5–10	16	17	18	19	11	12	13
<5	14	15	16	17	10	11	12

(c) Forecast and actual wind-chill on 27 March 1980 for Rushall Manor Farm

	Period (local time)						Total
	08–12	12–16	16–20	20–00	00–04	04–08	
Temperature (°C)							
forecast	10	10	10	7	7	7	
actual	12	11	9	7	6	7	
Wind speed ($m\ s^{-1}$)							
forecast	8	6	5	5	5	5	
actual	8	8	6	4	2	5	
Rain							
forecast	yes	no	yes	yes	yes	yes	
actual	yes	yes	no	no	yes	yes	
Wind-chill*							
forecast	16	11	14	14	14	14	83
actual	16	16	11	10	14	14	81

*Add the six scores to give the forecast 24-hour heat-loss factor M_{24}. If $M_{24} > 90\ M_B$ conditions may be critical; $M_{24} = 80$ to $90\ M_B$, danger; $M_{24} = 70$ to $80\ M_B$, warning; $M_{24} < 70\ M_B$, little danger.

It was evident from these initial trials that the main divergence of 'actual' from 'forecast' wind-chill factors could be attributed to the difficulty of forecasting the onset and cessation of precipitation, a problem likely to be accentuated, as will be seen, under showery conditions. Further, Mr Bishop suggested that, since the lamb coat tended to remain moist under 'dry' conditions in high humidity and low winds, future forecasts should allow for continuing coat wetness under appropriate conditions.

1982 season

The 1982 trial operated through RAF Benson and Bristol Weather Centre; the benign weather of early spring meant that the system was not given an adequate test. Only the first half of March yielded several high index days and it was during this period that Mr Dartnall's ewes began lambing near Marlborough.

Mr Dartnall commented subsequently as follows:

'... there were two periods when the indices were over 85, 9–12 March 1982 and the 14–17th. Several of the days in these two periods started dry and bright and during other lambings we would have turned some out. The high readings prevented us doing that and the weather duly turned bad in the afternoon. There is no doubt that if we had turned any out some would have been lost.'

At a meeting of all farmers involved in the 1982 trials Mr Dartnall referred to his loss of 43 lambs in a night in the 1981 season. A consequence of this was his adoption of the following choice of priorities for turning out lambs when there was pressure on housing in 1982.

Wind-chill factor	81–90	Turn out only single lambs
	71–80	Turn out twin lambs
	70 or less	Turn out triplet lambs.

'The result was an acceptable level of losses considering the high number of triplets born and a severe fox problem:

Ewes put to ram	2200
Lambs turned out	4048 (184%)
Lambs at inoculation	3855 (175.2%)
Lambs lost	193 (4.8%).'

Other farmers, although starting lambing in a mild period in the spring of 1982, also adjusted their management to take account of wind-chill. Mr Harbottle of Faccombe near Newbury, with fields at elevations of 150 m and 300 m, normally put stock out of a morning. He often delayed until the afternoon in the light of wind-chill forecasts and kept in triplets for several days, eventually putting them out in the more sheltered field at 150 m. Mr Hawes (Horton-cum-Studley, Oxon) found two occasions of high chill index when he did not turn out. He remarked, however, that if a flock is held in too long, virus infections can result. Mr Brown (Beckley, Oxford) said his mind was not altered by the forecasts. He felt that he could judge for himself when lambs should be put out.

Mr Soanes (Beckley, Oxford) felt the forecasts potentially useful but he began lambing in late March during the mild period.

Mr Bishop again found the forecasts 'extremely useful'.

1983 season

With the agreement of the Public Services Branch of the Meteorological Office trials were continued in 1983 free of charge and on a modestly increased scale. Several farmers from Hampshire, Surrey and West Sussex areas that fell in the Southampton Weather Centre catchment were involved, together with a Devon farmer (by local arrangement with Plymouth Weather Centre). The withdrawal of Benson from public service commitments meant that farmers in the Oxford, Berkshire and Wiltshire areas were served entirely by Bristol Weather Centre.

The weather of the season produced testing sequences for the system. To quote Mr M. J. Bibb, Bristol Weather Centre: 'It was a particularly difficult year with much of the precipitation being showery and as such it must have been a searching test of our effectiveness'.

The requirement on the forecasters to make a Yes/No forecast for rainfall over the 6 four-hour periods is, of course, the most demanding aspect of the forecast procedure. If the farm misses out on the showers, the actual wind-chill factor will be much less than the forecast value. This was partly resolved by taking:

(i) the probability of *light* showers as meaning 'NO' rain since the lamb could well shelter from a light shower or at least dry out quickly, and

(ii) the probability of *heavy* showers forecast as 'YES' rain.

As the season progressed Bristol decided to provide two wind-chill factors appropriate to this forecast shower severity. The farmer could interpret the factors accordingly.

Some comments by farmers on the 1983 season were as follows.

Mr N. M. Bridges, farm manager, Cirencester, wrote to Mr M. J. Bibb: '... we have reduced our mortality due to hypothermia this year in what is arguably one of the worst spells of weather at lambing for some years. I found it very useful to have very detailed weather forecasts and wind-chill forecast data to hand when making decisions on turn-out.'

In his report on lambing, Mr Bridges noted: 'Without doubt this service was a major aid in making the decision on when and what to turn out.

'Fourteen of the thirty-six days gave us forecast wind-chill factors of 80 or less, indicating it was of low risk to turn out ... we were forced to turn out ewes and lambs on days when the forecast factor was 81–88 although only strong lambs were put out on these days.

'Records show we only lost two lambs in the field due to exposure. We have without doubt reduced the number of deaths attributable to exposure following turn-out. A fair measure of credit must go to the staff of Bristol Weather Centre for their help.'

From Mr D. Harbottle, Faccombe Estates, near Andover, Hants: '... the trial forecast proved far more useful then last year although on several occasions what was forecasted failed to materialize and we held lambs in when they could have easily gone out.

'... we (Mr Harbottle and his new shepherd) felt that overall it was a very worthwhile exercise. Obviously it is very difficult for Bristol Weather Centre to be entirely specific some 60 miles east of them and therefore they must be inclined towards generalizations and this does fall down from time to time.

'However, I am sure that anyone lambing a considerable number of ewes with limited holding space must find the services beneficial.'

Writing to Mr K. Best of Southampton Weather Centre, Mr Janaway of Basingstoke commented: 'I found the figures you gave most helpful ...' (He suggested that a forecast for up to three days would be valuable since he had enough space to hold ewes and lambs for up to three days.)

The problems that can be posed by showery weather are highlighted in the pertinent comments of Mr Dartnall of Temple Farm, near Marlborough: '... Unfortunately I did not find the lamb wind-chill factor anywhere near as accurate this year as it was last. In many cases the figure was too high for the conditions that developed later that day; for example, on 29 March 1983 the factor was 97, when in fact we only actually had 2.5 mm of rain. There were several occasions when there was a very high figure and yet it was warm, humid and misty and yet on other occasions the same figure was followed by much colder, wetter weather. To me there was no comparison between the two days and yet Bristol Weather Centre forecast that they would be roughly the same. However, there was one advantage in actually physically talking to a meteorological officer. Whether the problem was in the interpretation of the data but it seemed to me that the quality of advice wasn't the same as the year previous.

'I think this system still has potential but needs refinements ...'

Bristol subsequently developed the 'two-index system' for the showery situation to minimize the likelihood of such errors.

The meteorological office at Plymouth responded to a request by Mr Allen, Lane End Farm, Honiton, Devon, who had read of the trial wind-chill forecasts in the farming press. He received these forecasts for three weeks from 20 March on a repayment basis. He reported the forecasts to be 'very, very useful — the timing too was spot on. I hope the service will continue'.

He considered the value to lie in aiding his decision to put out lambs, born in house, since the following night's weather was critical.

Verification exercise

A verification exercise was carried out by Southampton Weather Centre for the recipients, who were all in the north-east of Hampshire. Interpretations of maximum and minimum temperature from Long Sutton were therefore appropriate, together with subjective assessments of wind strength and rainfall from Southampton Weather Centre records and London Weather Centre's *Daily Weather Summary*.

Briefly, 7 of the 51 forecasts issued predicted the index exactly whilst the error of the remainder did not show a particular bias.

'As one would expect', commented Mr Best, 'the greatest forecast errors occurred on occasions when this precipitation prediction was unsuccessful ... the forecaster is faced with a Yes/No decision regarding rainfall and he is often uncertain whether intermittent precipitation is significant with respect to the wetting of a young fleece.'

(Bristol Weather Centre partly resolved this problem, as discussed earlier.)

Conclusion

The forecasting scheme has been tried out under a variety of conditions from benign (most of spring 1982) to severe (several nights in 1980, 1981 and 1983). In particular, the showery spring of 1983 highlighted difficulties, since the wind-chill factor is critically dependent on rainfall and its duration. Nevertheless, the availability of a forecaster to discuss such problems with the farmer and to suggest 'limits' for the wind-chill factor (depending on whether showers were likely to be heavy or prolonged or light and infrequent) was vital and was appreciated by several farmers. Over the three seasons of the trial it was clear that farmers were prepared to adjust their management in the light of the wind-chill forecasts and on several occasions lamb mortality due to exposure was apparently dramatically diminished.

The scheme will overestimate the wind-chill under daytime conditions of strong insolation (conditions in which the index is likely to be low). It is under severe night-time weather that the index is more realistic, integrating as it does the effects of rain, wind and temperature.

The scheme tests the forecaster, yet does not make unreasonable demands upon him. It offers the opportunity for the forecaster to become involved with the participating farmer in his decisions, since interpretation of the wind-chill index (e.g. partitioning into day/night accumulation or the assessment of the consequences of showery conditions) may well be necessary.

At the current price of fat lambs, a charge for the service of about £100 (with possibly a reduction for those farmers who take the Meteorological Office Forecast Consultancy Service) must be seen as cost effective, representing as it does the value of perhaps three lambs.

The wind-chill forecast service was promoted in the area served by Bristol Weather Centre, through ADAS, for the 1984 lambing season.

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ADAS Livestock Husbandry Officers Mr G. Hughes, Miss R. Cox and Miss A. Perez recruited interested farmers — 10 farmers co-operated in the trials and many made constructive oral or written comments which are summarized in the article. The encouragement of the Public Services Branch of the Meteorological Office is acknowledged.

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Discomfort in Sharjah

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Summary

Three years' wind, temperature and humidity data at Sharjah International Airport are used to provide a climatology of 'effective temperature', interpreted as a 'discomfort index' including monthly means and diurnal variation. The summer climate (May to October) of Sharjah is shown to be more uncomfortable than that of Singapore and is worst in July and August when the effective temperature reaches dangerously high values. Regression equations are found for daily mean values of effective temperature as a function of dry-bulb temperature, wet-bulb depression and wind speed for all summer months. The 'accumulated physiological strain' of successive uncomfortable days is discussed.

Introduction

Sharjah is the third largest city in the United Arab Emirates. It is located less than 10 kilometres to the north-east of Dubai and is almost connected with Ajman. The city, which is situated on the south-eastern shore of the Arabian Gulf at 25° 19'N 55° 31'E, has grown very rapidly in the last few years.

The climate of the Arabian Gulf is known for its high temperature and relative humidity (see Fig. 1), truly considered as one of the most oppressive climates in the world. Two previous studies by Watt (1967) and Turner (1978) discussed climatic discomfort in Bahrain. This paper is an analysis of discomfort in Sharjah, especially in the six summer months.

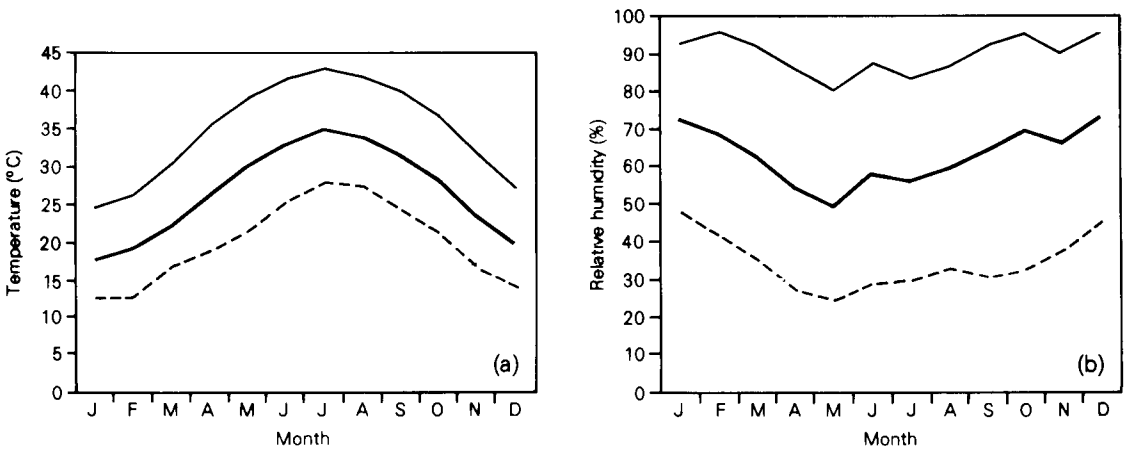

Figure 1. Annual variation of temperature and relative humidity at Sharjah. Graphs display (a) mean daily maximum, mean daily and mean daily minimum temperatures, and (b) mean daily maximum, mean daily and mean daily minimum relative humidities.

The climate of Sharjah

Sharjah is located in the hot arid desert climatic zone of the Arabian Gulf (BWh Köppen classification). Average annual rainfall, which does not reach 125 mm, is confined mainly to the winter

months. The year is generally divided into two parts; winter (November – April) and summer (May – October). The climate in winter is normally pleasant with a mean temperature of 21.5 °C. Mean daily maximum temperature is 29 °C and mean daily minimum is 15 °C. The coldest month is January which has an average temperature of 17.9 °C and a mean minimum temperature of 12.6 °C. Average relative humidity of the winter months is 66% and average wind speed is 7.95 knots. Average wet-bulb temperature is 17.2 °C and average 'effective temperature' (T_e), defined later, is 14 °C.

Climate in the summer months is extremely unpleasant with an average temperature of 32.4 °C and a mean relative humidity of 58% (Table I). Mean daily maximum temperature reaches 42.9 °C in July and on individual days the temperature not infrequently exceeds 49 °C.

Table I. *Monthly, seasonal and yearly means of dry-bulb temperature (T), wet-bulb temperature (T_w), relative humidity (RH) and effective temperature (T_e) at Sharjah International Airport for the period 1977–80*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Winter (Nov.–Apr.)	Summer (May–Oct.)	Year
T (°C)	17.9	19.1	22.4	26.3	30.4	33.3	35.3	34.5	32.0	28.9	24.4	20.0	21.5	32.4	26.9
T_w (°C)	15.0	15.8	17.6	19.7	22.0	26.2	27.4	27.4	26.2	23.9	18.7	16.7	17.2	25.5	21.3
RH (%)	73	69	63	54	49	57	55	58	64	67	65	73	66	58	62
T_e (°C)	10.0	11.0	15.0	19.0	22.5	25.9	27.4	27.3	25.5	22.6	16.0	13.0	14.0	25.2	19.6

Summary of data used

Climatological data used is from Sharjah International Airport which is located about two kilometres from the sea in the south-west of the city at an elevation of 33.3 metres above mean sea level. The means of daily dry-bulb and dew-point temperatures for the four summers of 1977–80 were used to estimate means of daily wet-bulb temperature from a hygrometric chart. Then, means of daily dry-bulb temperatures and means of daily wind speed were used in computing means of daily T_e from a nomogram of T_e. Readings of a three-hourly interval of dry-bulb temperature and relative humidity were used to compute the diurnal change of wet-bulb temperature.

The discomfort index

Of the many discomfort indices, T_e is the most widely used. It is a stochastic model that was formulated by the American Society of Heating and Ventilating Engineers (1944) and since then it has been used in many studies of human discomfort in tropical and semi-tropical areas. Several examples of these studies can be cited: Stephenson (1963), Wycherley (1967) and Finkelstein (1971). T_e, as defined by Stephenson, is 'that temperature of saturated motionless air which would produce the same sensation of warmth or coolness as that produced by the combination of temperature, humidity, and air motion under consideration'.

The scale of T_e is based on the reactions of groups of middle-aged people in Pittsburgh, Pennsylvania, to varying conditions of air temperature, relative humidity and wind speed in a controlled climatic chamber. The original scale was intended to be used for indoor conditions, but its use had been extended to outdoor environments provided that people are not exposed to direct sunshine, are suitably dressed and are not engaged in strenuous work.

It is recognized that the use of T_e as a discomfort index has several shortcomings, but a number of studies have shown that it depicts physiological reactions to atmospheric environment reasonably well.

It was found that physical impairment at high T_e has a parallel in mental performance. The following scale, which was considered by earlier authors to be suitable for acclimatized people in tropical regions is used in this study:

Comfort range	T_e (°C)
Above acceptable	>24.4
Upper acceptable	22.9 - 24.4
Optimum	20.5 - 22.8
Lower acceptable	18.9 - 20.4
Below acceptable	<18.9

Analysis of results

Annual variation of T_e

Monthly means of wet-bulb temperature and T_e are given in Table I.

It is clearly shown that winters in Sharjah are usually mild, comfortable for living and suitable for vacations and outdoor sports, not only for acclimatized people of the area but for Europeans and other peoples of the temperate regions. Winter period requires no further comment and all subsequent analysis is directed to the summer months.

Summers in Sharjah are extremely unpleasant and uncomfortable. Mean T_e reaches 25.2 °C and average wet-bulb temperature exceeds 25.5 °C. The two most oppressive summer months are the hot and sticky July and August. Average T_e of these two months reaches 27.4°C and frequently exceeds 30°C on a number of days*. On 4 August 1979 mean dry-bulb temperature was 36.6 °C and average relative humidity was 71%. The mean T_e on that day exceeded 31.5 °C which is commonly reported as a probable level at which heat stroke is likely to occur. Discomfort in May and October is considerably lower than its average in the rest of the summer months. The mean T_e in May is 22.5 °C, which makes it one of the relatively comfortable months. The expected number of uncomfortable days in May if 4.25 compared to 31 in August. The remarkable drop of relative humidity from 54% in April to 49% in May associated with the change in direction of the winds from the prevailing westerly or north-westerly Shamal winds to the southerly and south-easterly winds seems to be an important factor in this decrease of discomfort. The mean T_e of October is 22.6 °C and the expected number of discomfort days is 4.5.

Monthly means of T_e for Bahrain, Sharja and Abu Dhabi are shown in Table II. The most unpleasant month in the three places is August. Discomfort is highest in Bahrain and is lowest in Abu Dhabi. Means of T_e in August, September and October are higher in Bahrain than in Sharjah. However, they are higher in Sharja during May, June and July. The extreme oppressiveness of the climate in the coastal areas of the Arabian Gulf during the summer is clearly shown when means of T_e for these three Gulf cities are compared with those of an equatorial station like Singapore (Table II).

Table II. *Means of effective temperature (°C) at Sharjah, Abu Dhabi, Bahrain and Singapore*

	May	June	July	Aug.	Sept.	Oct.	Summer
Sharjah	22.5	25.9	27.4	27.4	25.5	22.6	25.2
Abu Dhabi	22	24	26	27	25	22	24.3
Bahrain	22	25	27	28	26	23	25.2
Singapore	25	24	24	24	24	24	24.2

Accumulated physiological strain

One of the main factors of discomfort that is insufficiently illustrated in the index of mean monthly T_e is accumulated physiological strain that results from a succession of days of discomfort. Table III gives four simple measures of monthly accumulated physiological strain. The first measure is the percentage

*Body temperature begins to rise when T_e exceeds 30 °C.

of the mean monthly number of days in which average daily wet-bulb temperature exceeds 25.5 °C. The second measure is the percentage of the mean monthly number of days in which T_e exceeds 24.4 °C. The third measure, which is the expected number of days of discomfort per month, is computed by use of the binomial distribution and treatment of the discomfort day as a Bernoulli variable. The fourth measure is computed by daily accumulation of the excess of T_e above 24.4 °C. Because the purpose of this measure is to assess accumulated physiological strain, days in which T_e is lower than 24.4 °C are ignored. To facilitate comparison between months of different lengths, the average monthly accumulated excess of T_e above 24.4 °C is multiplied by a correction factor that depends upon the ratio of a 30-day month to the actual number of days in the month. Another measure of accumulated physiological strain is given in Table IV. This measure is a matrix of probabilities of having different successions of uncomfortable days in a ten-day period. Probabilities in Table IV are computed for each month according to the binomial distribution.

Table III. *Measures of monthly accumulated physiological strain in Sharjah*

Accumulated physiological strain	May	June	July	Aug.	Sept.	Oct.
Percentage of days $T_w > 25.5$ °C	3	64	85	82	66	25
Percentage of days $T_e > 24.4$ °C	14	80	93	100	78	15
Expected number of uncomfortable days per month	4.3	24	28.8	31	23.4	4.6
Accumulated monthly averages of $T_e > 24.4$ °C	3.4	50	92.4	86.2	38.5	5.1

Table IV. *Probabilities of different successions of uncomfortable days in a ten-day period*

	Probabilities of different days (x)									
Month	$x \geqslant 1$	$x \geqslant 2$	$x \geqslant 3$	$x \geqslant 4$	$x \geqslant 5$	$x \geqslant 6$	$x \geqslant 7$	$x \geqslant 8$	$x \geqslant 9$	$x = 10$
May	0.80	0.46	0.16	0.05	0	0	0	0	0	0
June	1.0	1.0	1.0	1.0	0.97	0.88	0.78	0.68	0.68	0.11
July	1.0	1.0	1.0	1.0	1.0	1.0	0.99	0.97	0.85	0.48
Aug.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sept.	0.72	0.36	0.13	0.03	0	0	0	0	0	0
Oct.	0.80	0.46	0.16	0.05	0	0	0	0	0	0

The two months of least discomfort are May and September and the two most uncomfortable months are July and August. Although every day in August is an expected day of discomfort, the accumulated measure of discomfort in July (Table III) is larger than in August. Table V gives a frequency distribution of the uncomfortable days in July and August during the period 1977–80.

Table V. *Frequency distribution of T_e (°C) in July and August 1977–80*

T_e	< 20.4	20.5–22.8	22.9–24.4	24.5–26.9	27.0–29.4	29.5–32
July	0	1	8	31	68	16
Aug.	0	0	0	52	63	9

Factors of discomfort

Multiple regression offers an easy stochastic model for analysis of the relations between T_e and other related variables. It also results in a series of regression equations that can be used in computing T_e from these variables. A stepwise regression model is used in this paper to investigate the relations between average daily T_e and means of daily dry-bulb temperature, wet-bulb depression, relative humidity and wind speed. The correlation coefficients between T_e in each month and the other variables in the same

month are given in Table VI. The resulting regression equations for each month are listed in Table VII as are the *F*-ratios and the coefficients of determination which measure the percentage of explained variation in T_e.

Table VI. *Correlation between effective temperature (T_e) and dry-bulb temperature (T), wet-bulb temperature (T_W), wind speed (V), wet-bulb depression (T_{WD}) and relative humidity (RH)*

	T_e	T	T_W	V	T_{WD}	RH
May	1	0.90	0.68	0.09	0.40	0.29
June	1	0.62	0.66	0.49	0.03	0.14
July	1	0.73	0.79	0.15	0.10	0.22
Aug.	1	0.60	0.78	0.09	0.33	0.39
Sept.	1	0.56	0.78	0.13	0.25	0.16
Oct.	1	0.85	0.85	0.47	0.27	0.33

Table VII. *Regression equations, coefficients of determination (R^2) and F-ratios of mean daily effective temperature (T_e) upon daily means of dry-bulb temperature (T), wet-bulb temperature (T_W), wet-bulb depression (T_{WD}) and wind speed (V)*

Month	Equation	R^2	F*
May	$T_e = 0.91T - 0.31T_{WD} - 0.34V - 1.12$	0.95	827
June	$T_e = 0.78T - 0.41T_{WD} - 0.90V + 4.4$	0.78	139
July	$T_e = 0.94T - 0.48T_{WD} - 0.37V - 0.28$	0.92	475
Aug.	$T_e = 0.98T - 0.44T_{WD} - 0.35V - 2.0$	0.88	300
Sept.	$T_e = 0.91T - 0.49T_{WD} - 0.33V + 0.3$	0.80	159
Oct.	$T_e = 1.04T - 0.57T_{WD} - 0.31V - 3.9$	0.97	1380
Summer	$T_e = 0.96T - 0.43T_{WD} - 0.37V - 1.5$	0.94	4396

*All *F*-ratios in this table are significant at the 0.01 level of significance.

The general variability of T_e during the summer season is caused mainly by variability in dry-bulb temperature (Table VIII). Relative humidity is the second important variable but wind speed is a variable of minor importance. However, the relative importance of each variable changes considerably from one month to another; the discomfort in May and October is caused mainly by high temperature but in July and August by a combination of high temperature and high relative humidity. Wind speed remains a secondary variable during May, July and August but it becomes more important than relative humidity in June, September and October.

Table VIII. *Percentages of variation in effective temperature that are explained by variation in dry-bulb temperature (T), relative humidity (RH) and wind speed (V).*

R^2	May	June	July	Aug.	Sept.	Oct.	Summer
T	82	38	53	36	31	72	75
RH	07	13	29	31	06	17	13
V	06	17	11	08	22	17	03

Diurnal variation of wet-bulb temperature

As can be seen from Fig. 2, for the diurnal variation of wet-bulb temperature, there is no noticeable discomfort in the average days of May and October. While nights are generally comfortable in June and September, most of the day is uncomfortable in July and August. The least uncomfortable time of the day in July and August is early morning between 4.00 a.m. and 7.00 a.m. Wind speeds of three to four

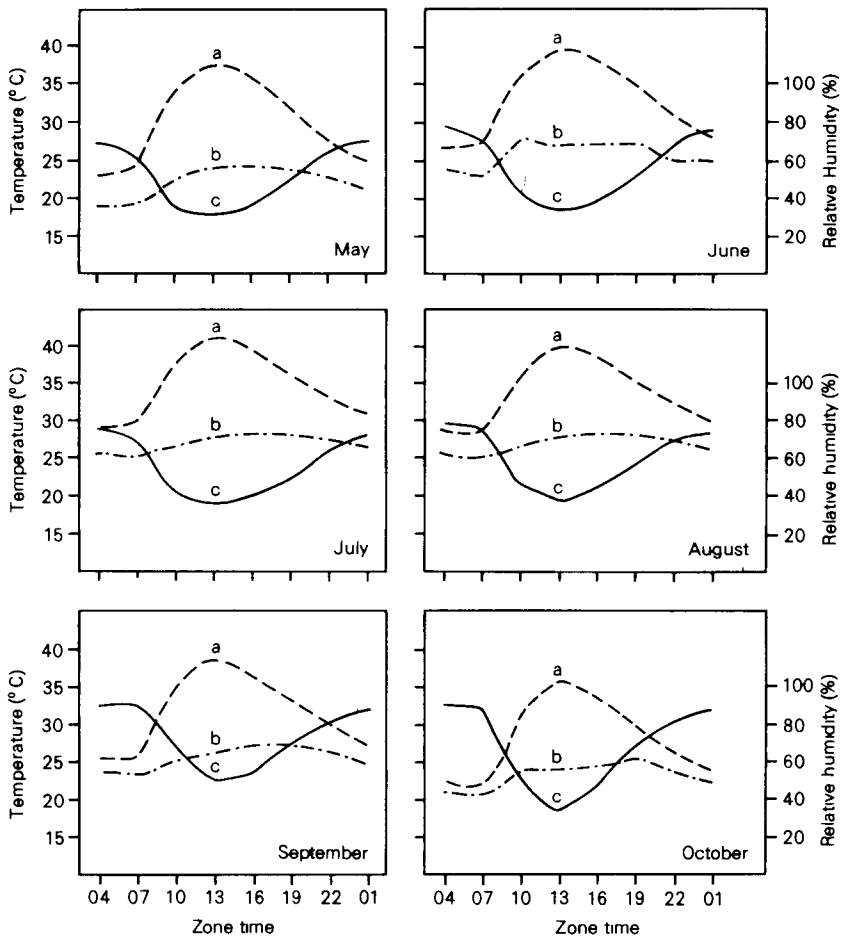

Figure. 2 Diurnal variation of (a) dry-bulb temperature, (b) wet-bulb temperature and (c) relative humidity at Sharjah.

knots are adequate for producing comfortable conditions in the early morning hours of July and August but winds of 15 knots are incapable of dealing with the more extreme conditions during most of the day (Fig. 3).

Conclusions

(1) The two most uncomfortable months in Sharjah are July and August and the least are May and October.

(2) Discomfort in May and October is caused mainly by high temperature, but in July and August it is caused by a combination of high temperature and relative humidity.

(3) Wind speed remains a secondary variable in the explanation of variability of T_e in May, July and August but it becomes more important than relative humidity in June, September and October.

(4) Summers in the Arabian Gulf region are more uncomfortable than summers in a typical equatorial area as represented by Singapore.

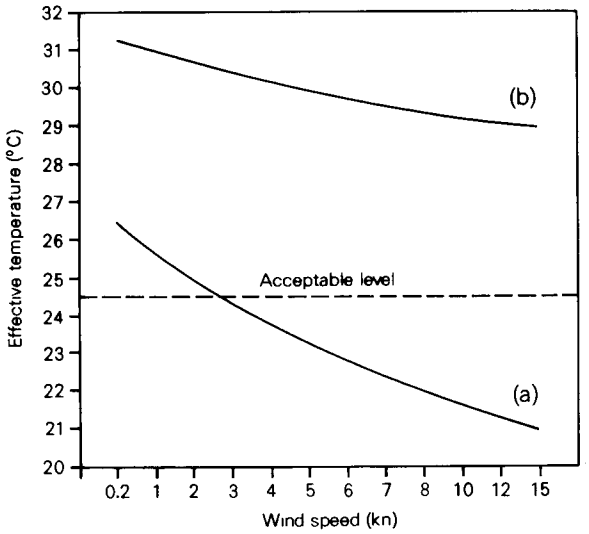

Figure 3. Variation of effective temperature with wind speed at Sharjah at (a) 0700 zone time and (b) 1300 zone time for an average August.

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551.509.329:551.586:632.11:632.3/.4

The use of meteorological data in plant disease warning schemes

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Summary

The agricultural section of the Meteorological Office has for a number of years provided an automated plant disease warning scheme to the Ministry of Agriculture, Fisheries and Food. An account is given of the comprehensive warning service now offered and is illustrated by a description of one of the most recent additions to the service, the combined plant disease program. Future developments are also discussed.

1. Introduction

It has long been realized that plant diseases are greatly influenced by the weather. Theophrastus (370–286 BC), for example, recognized that cereal crops growing in upland areas exposed to the wind were not so liable to rust (a fungal disease) as crops grown on the lowlands (Colhourn 1973).

Work carried out in recent years by plant pathologists and agricultural meteorologists has identified links between weather and the development of a number of plant diseases. In some cases it has been possible to define criteria for potential infection periods in terms of readily available meteorological variables. By combining this information with a knowledge of the growth stage of the crop and existing disease levels (including carry-over from previous years) plant pathologists are in a position to advise on both the need for spraying and its timing to achieve optimum effect.

2. Plant diseases and the influence of weather

Empirical relationships that identify weather conditions suitable for disease development have been established for several of the most important diseases including apple scab, barley mildew, eyespot, fireblight, net blotch, potato blight, *Rhynchosporium* and *Septoria*. All, apart from fireblight, are fungal diseases and have in common a sensitivity to weather at critical stages in their life cycle.

Temperature, humidity, rainfall and wind speed are the most important quantities in assessing disease risk. With apple scab, for example, the impact of raindrops causes spores to be released from fallen leaves into the air; these spores can then infect new tree growth by settling on the growing leaves so long as these remain wet (Adams and Seager 1977). This requirement is reflected in the criteria: a possible infection period starts when precipitation is reported, and continues as long as there is precipitation, or a dew-point depression of 1 °C or less is reported (taken to represent leaf surface wetness (Hearn 1961)). A so-called 'Smith period' occurs when this period satisfies a certain temperature/time condition (allowing for breaks of no more than one hour) as noted by Mills and La Plante (1954).

During 1982 a complex mathematical model of potato blight was introduced operationally to replace the existing empirical scheme. The new model (Sparks 1980) monitors, in simplified terms, the environmental effects on every stage of the life cycle of the disease from the growth of spores to the formation and senescence of lesions. The scheme is a significant step forward in disease-weather modelling and is the first of a new generation of sophisticated models which will gradually replace the existing empirical models.

3. Operational schemes

A number of computer programs incorporating associations between weather and plant disease have been written over a number of years, the first being for barley mildew in 1975. The programs are mostly run about mid-morning each day during the season of interest, accessing data for the previous 24 hours which have been passed into the synoptic data bank from stations throughout the United Kingdom. Output from the programs is in the form of a telex message which is dispatched to the Ministry of Agriculture, Fisheries and Food (MAFF) computer at Guildford about midday for subsequent access by their ADAS plant pathologists in each region. The data are also sent direct to the Crop Pest and Plant Disease Intelligence Unit at Bristol for interpretation (see Fig. 1). Certain routine messages are similarly telexed direct from Bracknell to the East of Scotland College of Agriculture and to the Department of Agriculture, Northern Ireland.

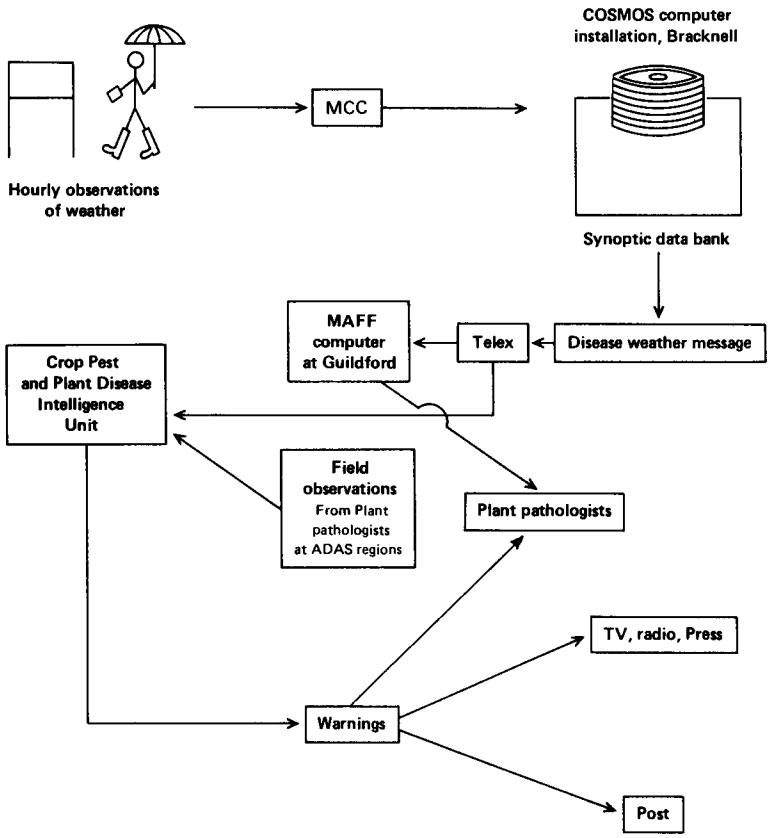


Figure 1. Flow of weather information to and from the Crop Pest and Plant Disease Intelligence Unit at Bristol. (MCC — Meteorological Communications Channel)

4. The combined plant disease program

In 1982 it was decided to rationalize the information provided and so a new plant disease message with the code-name HERDS was introduced on 1 January 1983. This message incorporates the most useful information from each of the four existing plant disease messages in a more convenient form.

A shortened version of the telex output is shown in Fig. 2 and the salient features are described in the Appendix. The full message contains data for almost 100 stations in the United Kingdom, of which 55 or so report hourly and can be used to derive the full complement of disease indices; the locations of these are shown in Fig. 3.

The HERDS program is run daily on COSMOS, the Meteorological Office's computer installation, at about 1045 GMT by which time four other programs producing the component data have already run. The steps involved are shown in Fig. 4. A paper copy of the output is produced for local quality control and storage in addition to the telex output. Output from HERDS is directed to an on-line data set which is then accessed by communications computers that dispatch the message to recipients with the assistance of an automated 'telex manager'.

PLANT DISEASE INFECTION					CRITERIA ON 21/05/1983										
	A	R	S	N	RAIN	0	BARLEY		EYE	POTATO			WET PERIODS		
	P	H	E	E		9	MILDEW		SPOT	BLIGHT			TIME	LEN	MEAN
	P	Y	P	T		D				MODEL			OF		TEMP
	L	N	T	B		P							END		DEG
STN NO	E	C	O	L	MM	D	SMTH	POL	WD	SM	SR	AIN	HRS	HRS	C
LER005	/	R2	S	2	0.4	1.6	33.4	1		/	0	13.1	12	022	6.2
KIR017	/	R1	/	2	+0.0	2.2	29.9	1		/	0	10.7	13	015	6.8
BEN022	/	/	/	2	0.3	2.2	34.7	1	56.3	/	0	11.2			
STO026	A	R3	S	1	1.9	0.4	29.5	0	96.0	/	0	11.9	18	024	6.8
KIN066	NM	R2	S	2	2.7	3.9	40.6	0	59.6	/	0	8.4	C.	017	7.2
GLE070					2.3	3.3	40.2								
WIC075	/	/	/	3	0.1	1.9	28.3	1		/	0	10.3			
DYC091	/	R1	/	2	2.3	4.1	36.6	0		/	5	6.9	22	011	8.3
FRA093					1.1	2.0									
TIR100	/	/	/	2	+0.0	3.5	41.4	2	92.2	/	0	18.4			
MCH111						0.0									
PRE135	/	/	/	1	+0.0	4.3	49.6	1	51.9	/	0	7.6			
WHI137					0.0	4.7	51.3								
ABT140	/	/	/	2	1.8	2.8	45.7	0	62.2	/	0	6.2			

Figure 2. An extract from a HERDS telex message.

5. Future developments of the disease warning scheme

Plant disease warnings are only one of a wide range of operational services based on recent weather data that are offered to MAFF and other sectors of the agriculture industry by the Meteorological Office. Other 'agromet' schemes include advice on certain weather dependent animal diseases, such as liver fluke and parasitic gastroenteritis, and advice on the airborne dispersion of virus diseases, e.g. foot-and-mouth. There is also a computerized service which provides weekly estimates of potential evaporation and soil moisture deficits for 40 km squares in the United Kingdom. Operational advice based on weather forecasts deals with certain insect pests and the hazards faced by animals owing to snowfall or windchill.

New applications for agromet data are continually being found and it is apparent that the present system of writing individual programs to meet each new requirement is not the most efficient way to satisfy the increasing demand for such data. The plant disease programs, for example, were written over a number of years and can be run totally independently of each other. This has the disadvantage that large program segments (and often the ones requiring most frequent change) are repeated in many of the programs. From a programmer's point of view, it is often easier to write a completely new program in order to compute a new index rather than add a few statements to one already in existence.

An alternative to the present system that is under development is illustrated in Fig. 5. The central feature is a large agromet data base containing, for a given period, both basic weather elements and derived parameters, such as the plant disease indices. Data are input to the data base via a series of data extraction and parameter-deriving programs. Once filled, the data therein would be accessible by any number of specific programs, e.g. ones to produce a telex message, paper or fiche copy of data, etc. The inherent advantage of this system is that changes can be made in one area without disturbing other areas, whilst new programs will only require the minimum of programming effort, using existing data extraction, telex formatting routines, etc.

One is aware of the limitations on the quality of advice attributable to the uneven distribution of the observing network (Fig. 3), especially in Scotland and Wales. These gaps will be filled as new observing sites occupied by Synoptic Automatic Weather Stations (SAWS) are established to provide synoptic data for forecasting and other purposes.

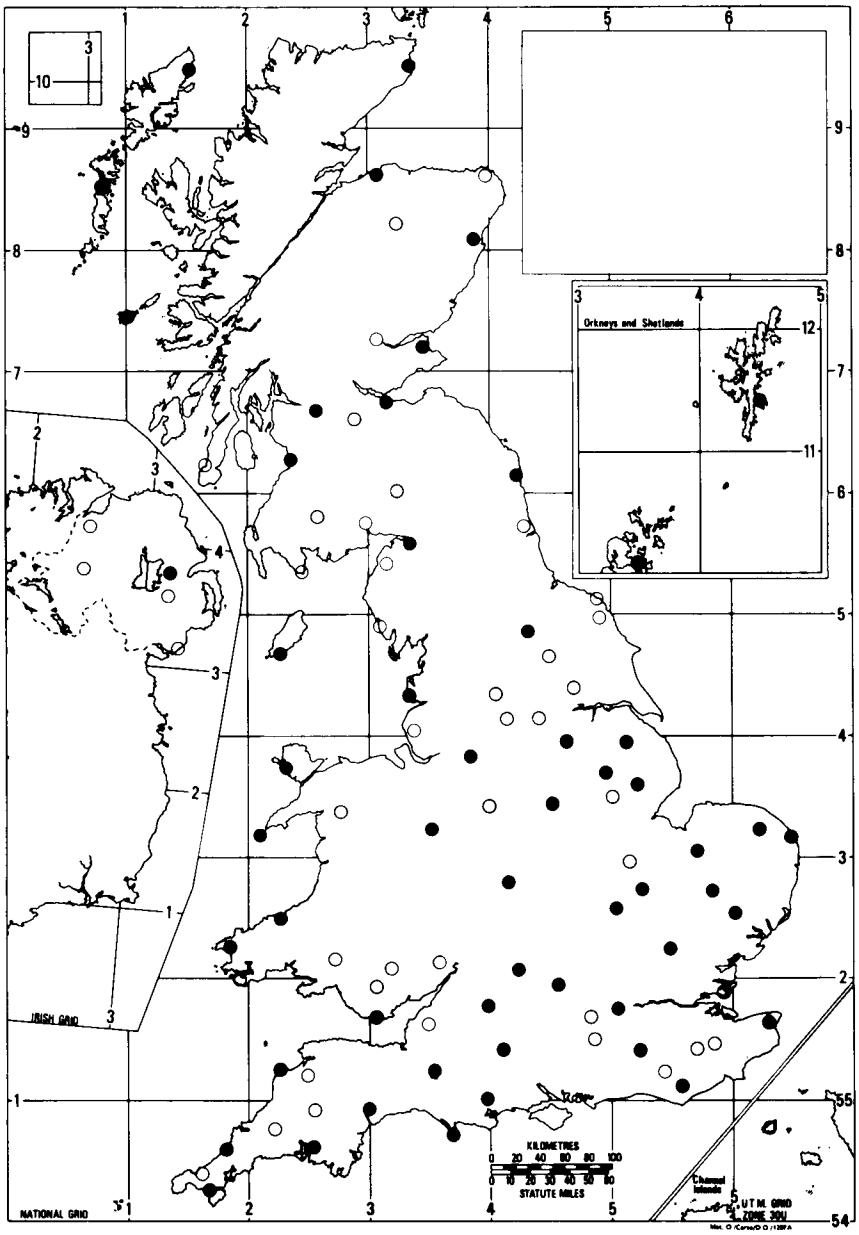
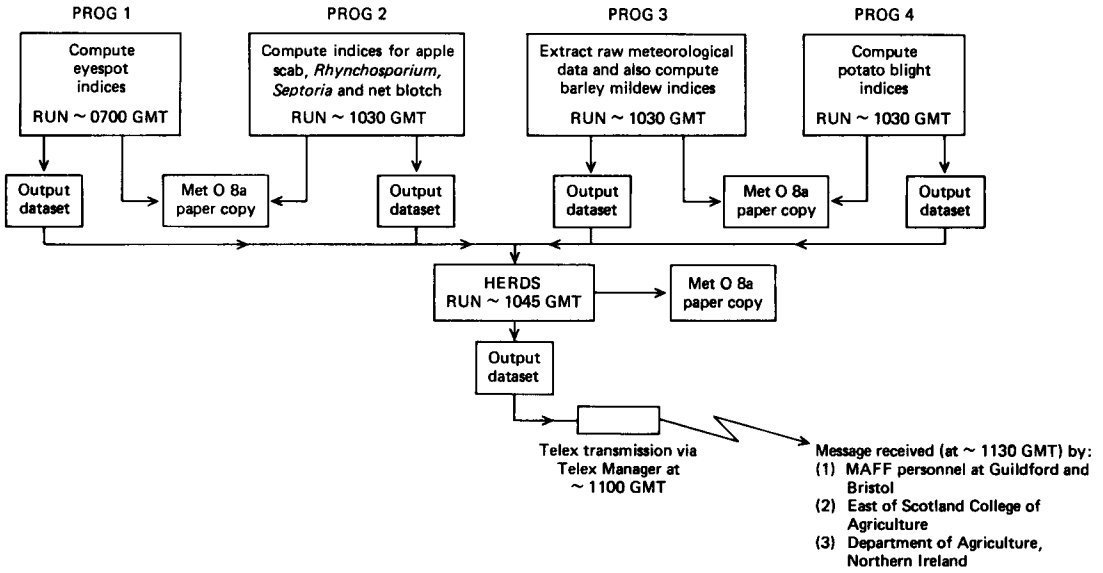


Figure 3. The location of stations included in the HERDS telex message.
• Stations with full complement of disease indices, o stations with a reduced complement.


PROG 1
Compute eyespot indices
RUN ~ 0700 GMT
PROG 2
Compute indices for apple scab, *Rhynchosporium*, *Septoria* and net blotch
RUN ~ 1030 GMT
PROG 3
Extract raw meteorological data and also compute barley mildew indices
RUN ~ 1030 GMT
PROG 4
Compute potato blight indices
RUN ~ 1030 GMT
Output dataset
Met O 8a paper copy
Output dataset
Output dataset
Met O 8a paper copy
Output dataset
HERDS RUN ~ 1045 GMT
Met O 8a paper copy
Output dataset
Telex transmission via Telex Manager at ~ 1100 GMT
Message received (at ~ 1130 GMT) by:
(1) MAFF personnel at Guildford and Bristol
(2) East of Scotland College of Agriculture
(3) Department of Agriculture, Northern Ireland

Notes

PROG 1 – Daily for the period from 15 January to 30 June.
PROG 2 – Daily for the period from 15 January to 31 July.
PROG 3 – Daily all year.
PROG 4 – Daily for the period from 15 May to 30 September.
These timings are subject to alteration. When 'out-of-season' a series of blanks will appear on the HERDS message under the headings for that particular disease.

Figure 4. Daily sequence of events in producing a HERDS telex message.

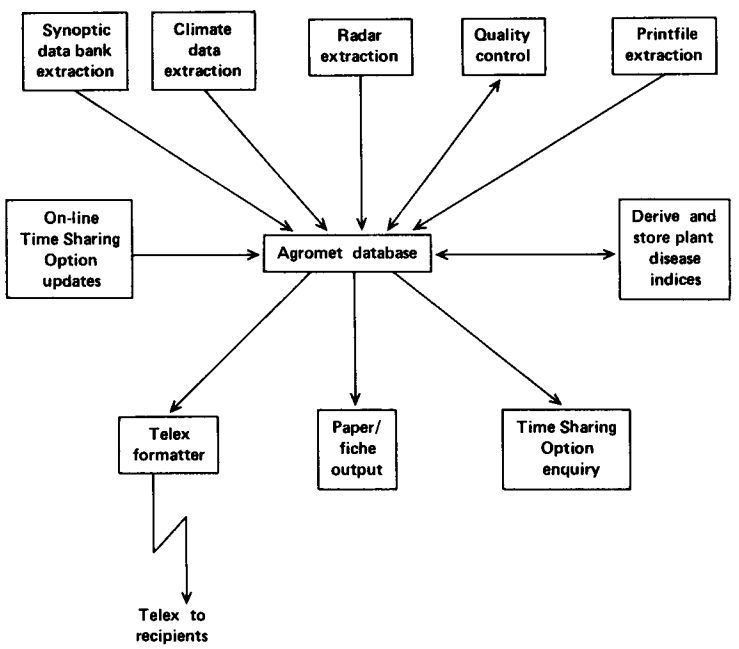


Figure 5. An alternative to the present agrometeorological data system.

6. Conclusions

The advice offered by the meteorologist forms an essential link in the chain of events that leads to timely and effective crop protection measures. Since the introduction of the first warning scheme for barley mildew in 1975 agrometeorologists have striven to increase the range and quality of the services they provide to the farming and horticultural community. This effort is reflected in the wide range of services now offered and by the increase in clientele who take advantage of them.

Major improvements in the advisory system are likely in years to come. The contrast between the open observing network of Fig. 3 and the crop environment information potentially available from satellites is considerable. The latter requires the Meteorological Office to develop the facilities to gather such data and also the software to turn the data into meaningful operational advice.

Acknowledgements

Thanks are given to Dr J. R. Starr, Regional Agrometeorological Officer at ADAS, Aberystwyth and to Dr N. Thompson, Head of the Agriculture Section, Meteorological Office, Bracknell for their constructive comments in the writing of this paper. Thanks also to Mr. R. D. D'Costa of the Agriculture Section for his assistance in programming the HERDS message. The information provided by Mr. W. R. Sparks, Regional Agrometeorological Officer at ADAS, Bristol helped greatly in the compilation of the Appendix.

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Appendix — Description of HERDS telex message

1. STN NO: The station identification code.
2. APPLE: The apple scab index.
   A — indicates that the requirements for at least light infection have occurred.
   NM — a 'near miss'. The criteria for light infection were not quite satisfied.
   / — conditions unsuitable for infection.
3. RHYNC: The *Rhynchosporium* index. R1, R2 and R3 indicate that conditions suitable for slight, moderate or severe infection occurred respectively. (/ takes the same meaning as before.)
4. SEPTO: The *Septoria* index. The symbol S indicates the possibility of *Septoria* infection.
5. NETBL: The net blotch index. 0, 1, 2 or 3 may appear, where 3 indicates the highest risk of infection.
6. RAIN: The total rain (millimetres) over the rainfall day. (+0.0 indicates trace)
7. 09DPD: The 0900 GMT dew-point depression (°C) on the day of the message.

8. BARLEY MILDEW: Two indices are calculated:

   SMITH — The Smith index involves the combination of several relevant weather variables. Interest is in the departure from some threshold value of the index.

   POL — The Polley index. The scale 0, 1, 2 or 3 is used to indicate an increasing risk.

9. EYESPOT: WD is a measure of the infection risk. Again threshold values are significant.

10. POTATO BLIGHT MODEL: Several variables are derived.
    The Smith period calls for suitable weather on two successive days.

    SM — The indicator P (partial) in the daily weather bulletins is used to show weather consistent with disease build-up. NM indicates a near miss. / indicates criterion not met.

    SR — an index of viable spore release from each active lesion.

    AIN — a measure of the accumulated infection.

11. WET PERIODS.
    Certain plant diseases require an obligatory period of leaf wetness for part of their life cycle.

    TIME OF END — the time of end of the wet period to the nearest hour. '00' signifies a period ending at midnight and 'C' a period continuing into the next day's message.

    LEN — duration (length) of wet period in hours. This observation accumulates continuously wet periods over several days if necessary.

    MEAN TEMP — the average temperature (°C) for the wet period.

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Onset of the summer monsoon over India and its variability

By I. Subbaramayya, S. V. Babu and S. S. Rao

(Department of Meteorology and Oceanography, Andhra University, Waltair, India)

Summary

The 'northern limit of the monsoon' (NLM) on a daily basis is determined using the principle stated by Subbaramayya and Bhanukumar (1978) with a slight modification for the period 1 May to 15 July in the years 1956–80. Thence the average dates of onset of the monsoon and their variances have been evaluated for several places. The advance of the monsoon is critically examined. Periods and places of stagnation of the NLM recurring regularly every year have been noted. Three significant phases in the advance of the monsoon over south peninsula, north peninsula and central north India respectively have also been identified.

The dates of onset in different parts of the country and the stagnation of the NLM are statistically investigated.

Abnormalities in the onset of the monsoon, either late or early, have been noted to be similar in general in any year over north peninsula, central India, Gujarat and north-east India, while in other areas it may not be the same.

Introduction

A chart showing the normal dates of onset of the summer monsoon over India was published by the India Meteorological Department (IMD 1943). The dates of onset at any station for the purpose of preparation of this chart were determined from the characteristic rise in the cumulative curve of the five-day mean rainfall totals. This so-called characteristic rise, however, is not clear at several of the stations. Therefore, Ananthakrishnan *et al.* (1967) inquired into the details of the procedure — adopted by the India Meteorological Department — and found that the onset date was determined subjectively by three experienced meteorologists for every year by keeping some other factors also in view and probably the mean of these dates was also taken into consideration in finalizing the normal dates of onset.

With the view of evolving a specific guiding principle to determining the onset date and the 'northern limit of the monsoon' (NLM) in any year, Subbaramayya and Bhanukumar (1978) studied the changes in different weather parameters one week on either side of the officially declared onset dates at a number of stations. It was observed that substantial changes in the weather do occur around the time of the onset, but not simultaneously. It was noted that the changes occur, in general, in the order: (1) medium and high cloud amounts, (2) low cloud amount, (3) rainfall, (4) maximum temperature and diurnal range of temperature. The changes were spread over four or five days and sometimes they were gradual too. Therefore, it was concluded that it may not be possible to have a simple criterion for fixing the onset involving several weather parameters. Hence they suggested that the onset of the monsoon at any place should be associated with the first westward moving rain storm of the season, for the reason that the monsoon rains are caused by easterly disturbances, in contrast to the winter and pre-monsoon rains which are associated with westerly disturbances.

It was, however, seen that easterly disturbances are present in the extreme south of India even in the pre-monsoon period (Subbaramayya and Ramanadham 1981), but the equatorial westerlies as a broad belt are not observed with those systems in the pre-monsoon season. Therefore, the presence of a belt of equatorial westerlies over the neighbouring oceanic area should also be considered as an additional condition in fixing the date of onset of the monsoon in the extreme south.

In the present study, the authors determined the NLM, based on the above guiding principle, every day from the beginning of May in the years 1956–80. Thence a revised chart of the mean dates of onset of the south-west monsoon for the Indian region has been prepared and the variability of the onset dates also has been studied.

Data and analysis

Daily rainfall amounts at about 300 stations during the period 1 May to 15 July in the years 1956–80 have been plotted on charts to study the rainfall distribution and the spreading of the rain areas day by day. To understand the synoptic systems, if any, that have contributed to the widespread rains on any day, the surface pressure and wind charts published in the *Indian daily weather reports* have been consulted. Rain areas associated with the westward progression of synoptic systems are demarcated. The NLM on any day is then obtained by joining the northernmost segments of the rain-area demarcation lines till that day. As an example the chart showing NLM on different days in the year 1969 is presented in Fig. 1.

About 200 stations uniformly spread over the country have been selected and the dates of onset of the monsoon at every station in every year from the NLM charts have been obtained. The average and the standard deviation of the dates of onset at every station have been evaluated. Correlations between the dates of onset at different stations also have been evaluated to study if there are any regional relationships.

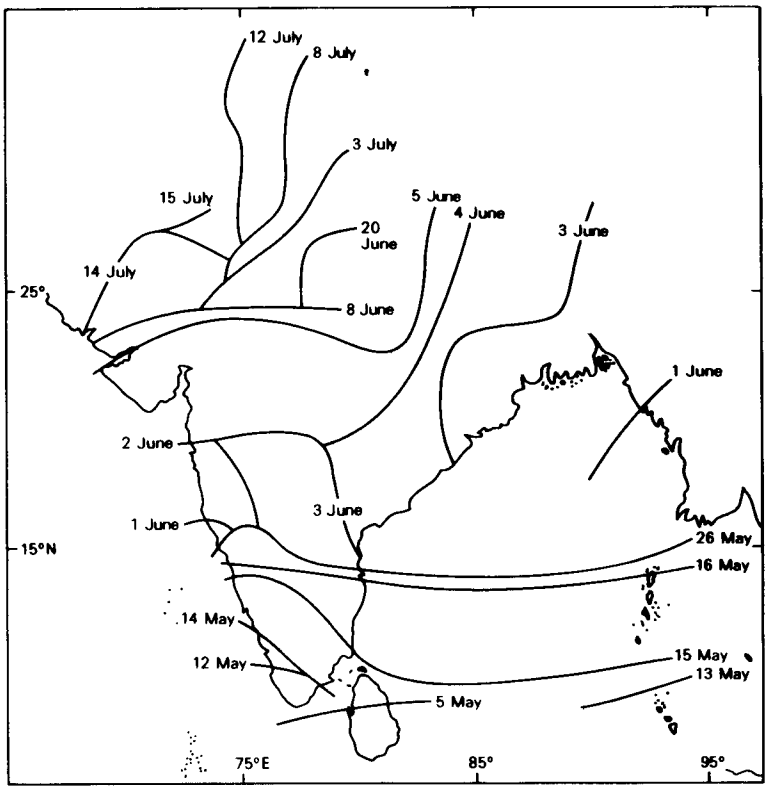

Figure 1. Advance of the monsoon in 1969, showing the northern limit of the monsoon on different days.

Results and discussion

The average dates of onset of the monsoon in different parts of the country evaluated by the above procedure are presented in Fig. 2(a). The normal dates chart published by IMD in 1943 is presented in Fig. 2(b) for purpose of comparison. Though the charts are similar, there are significant differences too. The average dates of onset on the present chart are early compared with those given by IMD over south peninsula and Sri Lanka by five to ten days. This difference could be due to the fact that the onset in the present study is considered to have been associated with the first westward moving rain storm while the IMD meteorologists were probably waiting to ensure the persistence of the rains. However, over central India and the adjoining northern parts, the dates agree, while over northern India the average dates of onset are later than those given by IMD. The IMD meteorologists in this case might probably have mistaken some of the rain spells caused by westerly troughs as monsoon rain when fixing the dates of onset over north-west India and hence the difference over the north-western region.

The monsoon advances mainly northwards over western India and westwards over the northern parts of the country. The orientation of the lines of dates of onset over peninsular India shows that the monsoon sets in earlier over the west coast than over the east coast at the corresponding latitudes. This feature is contrary to that in the IMD chart. The onset over eastern Bay of Bengal is, however, earlier to

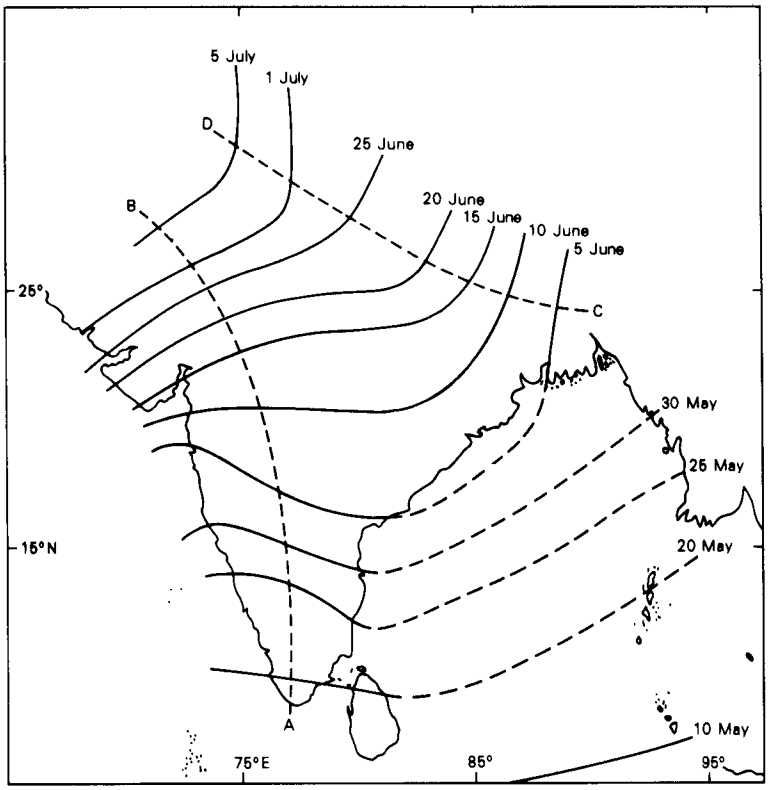

Figure 2(a). Average dates of onset of the south-west monsoon.

that over the west coast. The advance of the monsoon near the west coast was in general associated with northward movement of cyclonic disturbances over east Arabian Sea while the advance over the east coast was associated with development of low-pressure systems over north-west Bay of Bengal. The former event, in general, preceded the latter.

It can be seen that the advance of the monsoon is quick in the south but slow over central peninsula near 15°N. It is again quick over north peninsula and slow over Gujarat area in the north-west. The advance is also slow over Bihar in the north-east. The slow advance in the above areas was in fact due to stagnation of the northern limit of, or break in the advance of, the monsoon by one to two weeks in individual years. It is only in the averaging process that it appears as a slow advance. The northward progression of the monsoon over India in individual years along the lines AB and CD (shown in Fig. 2) is presented in Fig. 3. It clearly shows the breaks in the advance of the monsoon. The average period of the stagnation in different regions and the average latitude/longitude of occurrence of stagnation have been evaluated. The stagnationof the NLM over central peninsula occurs at 14°N from 22 May to 6 June (15 days) on the average while that over the Gujarat area is at about 24°N from 13 to 30 June (17 days).

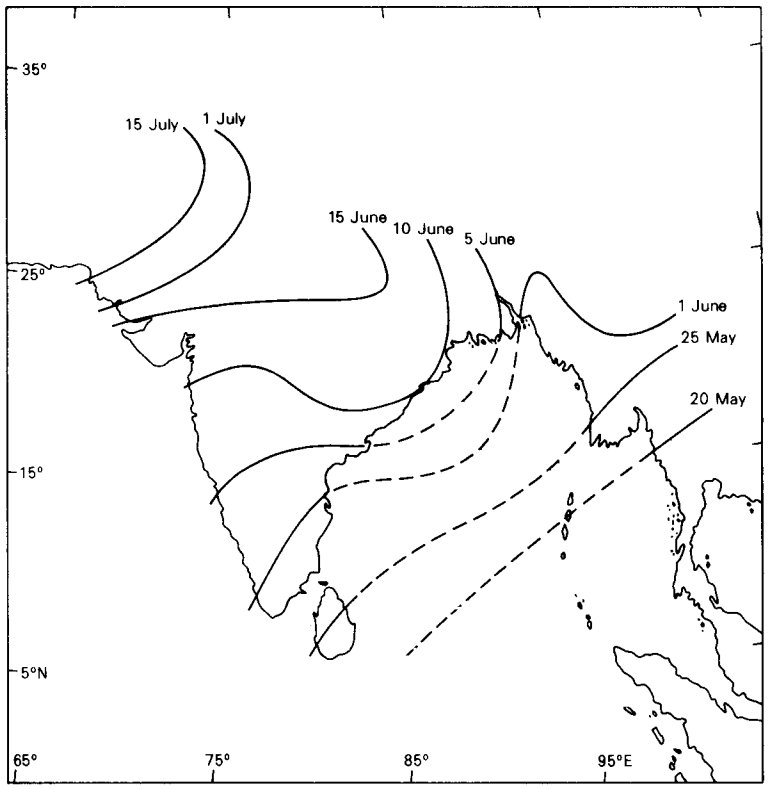

Figure 2(b). Normal dates of onset of the south-west monsoon (India Meteorological Department 1943).

The break in the westward advance over north-east India occurs on the average at 86°E from 6 to 17 June (11 days). There is a less conspicuous break of 12 days duration in the westward advance at 79°E. These features of the advance of the monsoon are represented in Fig. 4.

Stagnation of the NLM over Sri Lanka was also observed in some years. It may be a regular yearly feature, and occurring in other years further south of Sri Lanka, which could not be identified because of lack of data south of Sri Lanka. One can thus see that there are mainly three spurts or phases in the advance of the monsoon over the Indian subcontinent; first over south peninsula, second over north peninsula and central India and the third over the central parts of north India.

The variability of the onset of the monsoon as expressed by the standard deviation of dates of onset is presented in Fig. 5. It is large (ten days) over the west coast and north-east India and relatively small (eight days) over the monsoon trough area. There were, however, instances when the monsoon was delayed by even three weeks in individual years.

The correlations between the dates of onset at 15 stations spread over the whole country showed that they are in general positive, but large significant correlations appeared at some adjacent stations only.

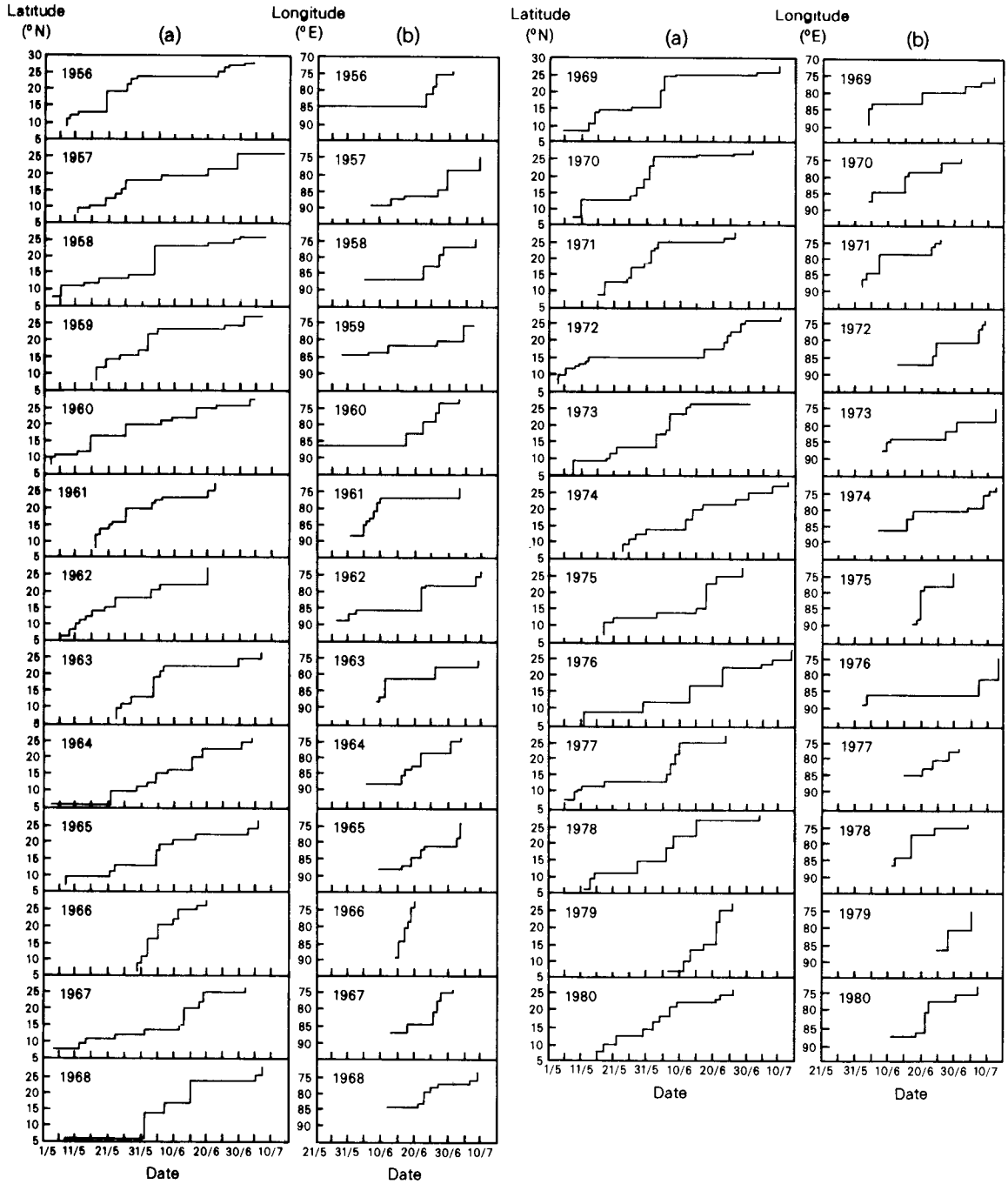

Figure 3. Advance of the monsoon along (a) the line AB and (b) the line CD shown in Fig. 2 (a) in the years 1956–80.

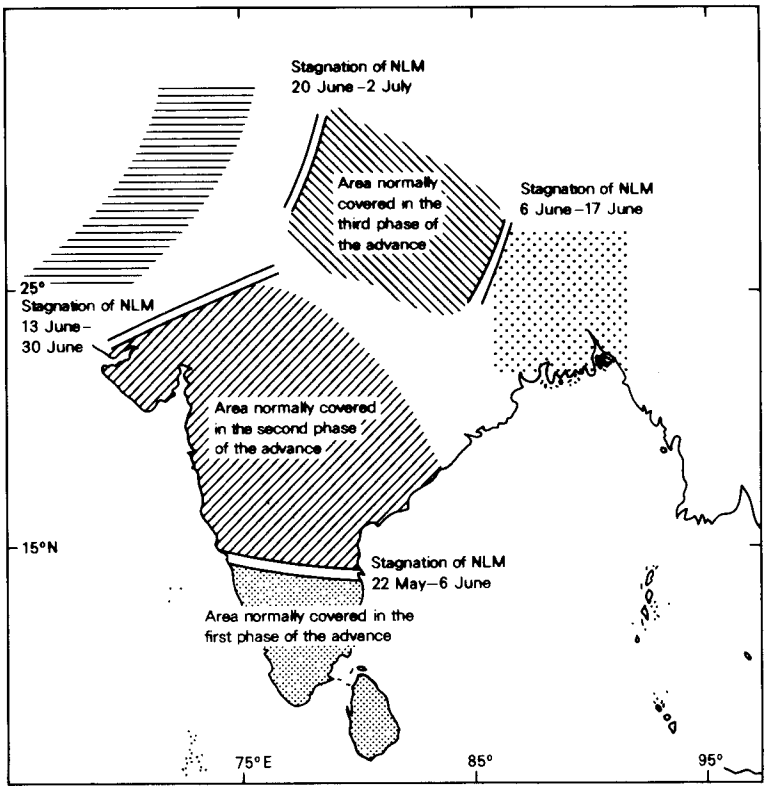

Figure 4. Areas and periods of different phases in the advance of the monsoon.

These stations fall into three groups, and area-wise they are in south peninsula, north peninsula and north-east India and north-west India. These are the areas where the three phases in the advance of the monsoon have been found to occur and this explains the large correlations between the stations in each area.

Further, correlations between the onset dates, P_1', P_2', etc., at representative stations in different phases of quick advance of the monsoon, and duration of the stagnation of NLM, S_1', S_2', etc., at different places also have been evaluated and are presented in Table I. It can be seen that the onset date in any phase of advance bears large negative correlation with the duration of the following stagnation period and positive correlation with the proceeding one. This means late/early onset in any phase is partly caused by an earlier prolonged/short stagnation, while the same causes short/prolonged stagnation later. It is interesting to note that there are significant positive correlations between (i) dates of onset over south peninsula, P_1, and north-east India, P_1', (ii) period of stagnation over Gujarat, S_2, and that over Bihar, S_1', as well as the onset date over central north India, P_2', and (iii) dates of onset over north peninsula, P_2', and central north India, P_2'. The latter two indicate that the advance over north peninsula and central north India and the stagnation over Gujarat and north-east India are affected by a common factor. The stagnation, S_2, over Gujarat has significant negative correlation with that over central peninsula, S_1, and the onset date over north-east India, P_1'.

Table I. *Correlations between dates of onset and periods of stagnation of the monsoon*

	P_1	S_1	P_2	S_2	P_3	P_1'	S_1'	P_2'	S_2'	P_3'
P_1		-0.49	0.33	-0.23	0.04	0.43	-0.27	0.13	-0.28	-0.10
S_1			0.69	-0.48	0.08	0.20	0.06	0.29	-0.08	0.23
P_2				-0.71	0.12	0.03	-0.16	0.48	-0.30	0.16
S_2					0.61	-0.66	0.45	0.45	0.33	0.27
P_3						-0.21	0.45	0.25	0.12	0.57
P_1'							-0.20	0.16	-0.21	-0.09
S_1'								0.62	-0.28	0.36
P_2'									-0.33	0.39
S_2'										0.52

P_1 — Date of onset over south peninsula (Bangalore)
P_2 — Date of onset over north peninsula (Parbani)
P_3 — Date of onset over north-west India (Jodhpur)
P_1' — Date of onset over north-east India (Tura)
P_2' — Date of onset over north India (Lucknow)
P_3' — Date of onset over north-west India (Patiala)
S_1 — Duration of stagnation period over central peninsula
S_2 — Duration of stagnation period over Gujarat
S_1' — Duration of stagnation period over Bihar
S_2' — Duration of stagnation period over Punjab.

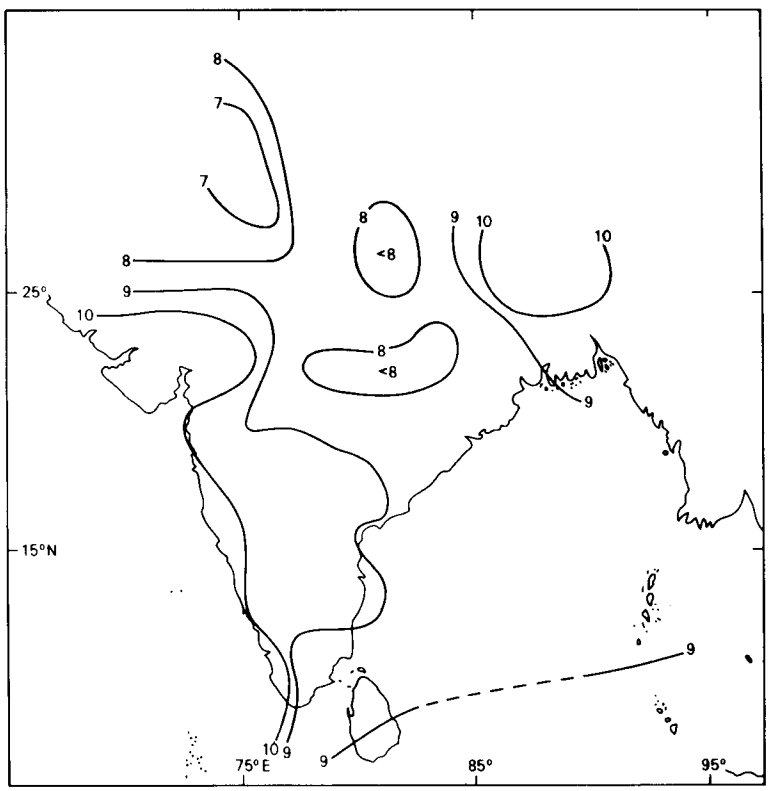

Figure 5. Variability of the onset of the south-west monsoon as expressed by the standard deviation of the dates of onset.

Conclusions

(1) According to the principle proposed by Subbaramayya and Bhanukumar for identifying the monsoon rains, the average dates of onset of the monsoon are five to ten days ahead of the dates given by IMD over south peninsula and late over north-west India.

(2) The advance of the monsoon takes place mainly in three phases, the first one being over south peninsula, the second over central India, both occurring in the northward direction, while the third is in the westward direction over north India.

(3) Stagnation in the advance of the monsoon for periods ranging from one week to two weeks occurs over central peninsula, Gujarat and Bihar regions.

(4) The variability of the onset of the monsoon in terms of standard deviation ranges from eight to ten days. Minimum variability is over central India.

(5) Correlation between the dates of onset of the monsoon in different parts of the country indicate that the onset and advance of the monsoon over north peninsula, central India, Gujarat and north-east India are generally uniformly affected in any year.

(6) It is, therefore, desirable to consider places situated over central India for the study of year to year variations of the onset of the monsoon, but not over Kerala area.

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Notes and news

A weather radar for flood warnings and improved short-period forecasts over London and south-east England

A contract has been placed with Plessey Radar Limited for the purchase and installation of a weather radar which will be used to help in detecting and forecasting potential flood situations in the Thames Water Authority, GLC and Southern Water Authority areas and to improve the accuracy of short-period weather forecasts in south-east England. A Consortium consisting of the Meteorological Office, the GLC, Thames Water Authority and Southern Water Authority are sharing the cost of the radar which will be sited to the north-west of London at RAF Chenies, near Amersham, Bucks. The site was chosen because it allows a clear radar view of London and the south-east of England.

A tower on which the radar antenna is to be mounted was completed recently. Installation of the antenna and its protective radome began on 6 February 1984 and should be completed by late April. The radar will come into operation in the early summer.

The total cost of the scheme will be about half a million pounds and it consists of a weather radar, data processing equipment and telemetered rain-gauges. The radar will scan continuously, detecting rain, hail or snow over a range of up to 130 miles and quantitative measurements of rainfall will be made up to a range of about 50 miles. Rainfall measurements over river catchment areas will be sent to the Water Authority control centres, and to the GLC Thames Barrier Control Centre where they can be presented on colour television monitors and are available to use in computer models as an aid to flood forecasting and to help in deciding on actions to be taken. These radar-derived data can also be used in the Water Authority operational hydrological control systems to help in the management of the water within rainfall catchment areas, as further information in river level regulation activities, and to obtain early warning of particularly heavy rainfall or thunderstorm events.

The measurements will also be transmitted back to the Meteorological Office Radar Research Laboratory at Malvern where they will be integrated with data from the existing network of four weather radars covering most of England and parts of Wales. There the information is combined in a central computer and a picture of the rainfall is produced displaying the weather in every 3 mile (5 km) square within range of a weather radar. A new picture is formed every 15 minutes, and by following these detailed pictures combined with other forms of weather observations from weather stations and satellites and the coarser scale computer predictions, the weather forecaster should be able to produce greatly improved short-period weather forecasts over the following two to six hours. It is hoped to illustrate the usefulness of the radar data in weather forecasting by including the display in national television weather presentations later this year.

A press facility will be provided at RAF Chenies when the radar system is brought into service. Further information can be obtained from the Chairman of the London Weather Radar Project Consortium Steering Group, Dr P. Ryder Tel: Bracknell (0344) 420242 Ext 2575.

Obituary

We regret to record the death on 17 January 1984 of I. H. Simpson, Higher Scientific Officer, Eskmeals. Ian Havron Simpson — always known as Sandy Simpson — joined the office as a Scientific Assistant in 1947. After a period of initial training and service with the RAF, he was posted to the Falkland Islands at the end of 1950 and in January 1954 he was seconded to the Falkland Islands Dependencies Survey for a further 18 months before his first posting to Eskmeals. In 1963 he was promoted to Senior Scientific Assistant and moved to Porton. Promoted further to Experimental officer in 1968 he had postings to Upavon and Larkhill before returning to Eskmeals in 1976 as Senior Meteorological Officer.

Sandy Simpson was a member of IPCS Branch Council in the 1960s and 70s, serving as Overseas Secretary and Editor of the Branch Bulletin. He was a keen fell-walker and a strong supporter of outdoor activities of all sorts, and also did a great deal for the young people of the village of Bootle where he lived.

With a keen appetite for work and a strongly marked personality, Sandy was not always the most peaceful of colleagues, but his generous nature and good humour usually smoothed out difficulties quickly.

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